# Performance measurement for intermodal corridors: a methodological approach

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## INTRODUCTION

Between the years 1996-1997 restructuring of rail and intermodal transport in Mexico began, giving several positive effects in terms of land freight movement in the country and certainly beneficial and also with encouraging results shown in the gradual but steady increase of the cargo volumes by rail, which has happened in the period 1995 - 2012, changing from 18.5% to 25.4% of the tonne-kilometers moved by surface transport in the country. Meanwhile, the road freight transport remains dominant, but their participation in the indicated period fell nearly 7% in relative terms going from 81.5% to 74.5% of the surface cargo transportation.

Nevertheless, for reasons of uncertainty in the liability to provide reports and data relating to the operation of rail and intermodal transport, as well as the confidentiality of information referred on the legal frameworks of the securities or agreements concession granted by the government of the Republic, the companies that own them have no obligations to provide information on the origin-destination of the cargo, the boxcars utilized, distances traveled on corridors, etc., so a big gap was produced regarding the availability of detailed data to allow out regular monitoring of the behavior of the rail freight sector and in particular, intermodal transport, one of the most dynamic sub-sectors over the past decades.

This occurred in the period 1997-2011, being the latter year in which the Technical Specialized Committee on both Economic and Operative Information from Transport (CTE-IEOST), created by the SCT and INEGI, started up, with a specialized group devoted to develop a methodology to build an origin-destination matrix for rail freight, with collaborating staff from the Directorate General of railways and Multimodal Transport (DGTFM-SCT) and researchers from the Mexican Institute of Transportation (IMT). This working group provided data and statistical information for the 2010-2012 period thus initiating the knowledge of the spatial distribution of the flows origin - destination intermodal freight in Mexico (García et al, 2012).

It is worth noting that the concept of intermodal transport, includes mainly those cargo flows of containers moved in the land part, both by rail and by road transport, the latter in what is known as "the last mile". By using different modes of transportation, intermodal transportation utilizes varying combinations, such as:

ÅShip - rail - road transport

ÅRoad transport - rail - road transport

Given the importance of this sector, this paper aims to make a methodological proposal to the regular and systematic analysis of intermodal corridors, by collecting hard data of origin-destination of the cargo, as well as the identification and the spatial representation of flows transported across the Mexican intermodal network, and the modeling into a georeferenced territorial system, as well as the development of performance indicators with a comprehensive and integrated approach to measure consistently and periodically the performance and efficiency of the corridors, in order to provide inputs for planning and decision-making for institutions and businesses in the areas of transport and logistics

## 1 IMPORTANCE OF INTERMODAL TRANSPORT IN MEXICO

Intermodal transport is still an incipient sector in the country, but its importance and growth potential is recognized to such an extent that it is given priority status within the National Development Plan 2013 - 2018 (Plan Nacional de Desarrollo, 2013).

It is clear that the development of intermodal transport reflects a trend towards the integration of functions and system optimization. This does not mean that the efficient operation of each of the modes is not important in itself, but it becomes secondary in relation to the efficiency of the system itself  (Burkhalter, 1999)

Intermodal transport involves in the land segment mainly rail transport, which is able to mobilize significant volumes of cargo, making it highly sustainable compared to trucking (Martner, 2008). From the economic standpoint, the  intermodal cost is lower and therefore the competitiveness is favored; from the social perspective vehicular load is diminished on the roads, accident rates are reduced and therefore the  mortality rates due to road accidents; and in environmental terms, the generation of emissions is significantly lower.

As San Martín (1997) states: "It is proven that the railroad has significant comparative advantages over the truck for transportation over long distances. Thus, to maximize the benefits of the container, it was necessary to integrate to the railroad as one of the major players in intermodal transportation system "..." The tremendous technological innovation that created the rail cars capable of carrying double container on a platform, "Double stack train" substantially improved the efficiency of land bridges and intermodal corridors, revolutionizing international trade logistics" (San Martin, 1997:12).

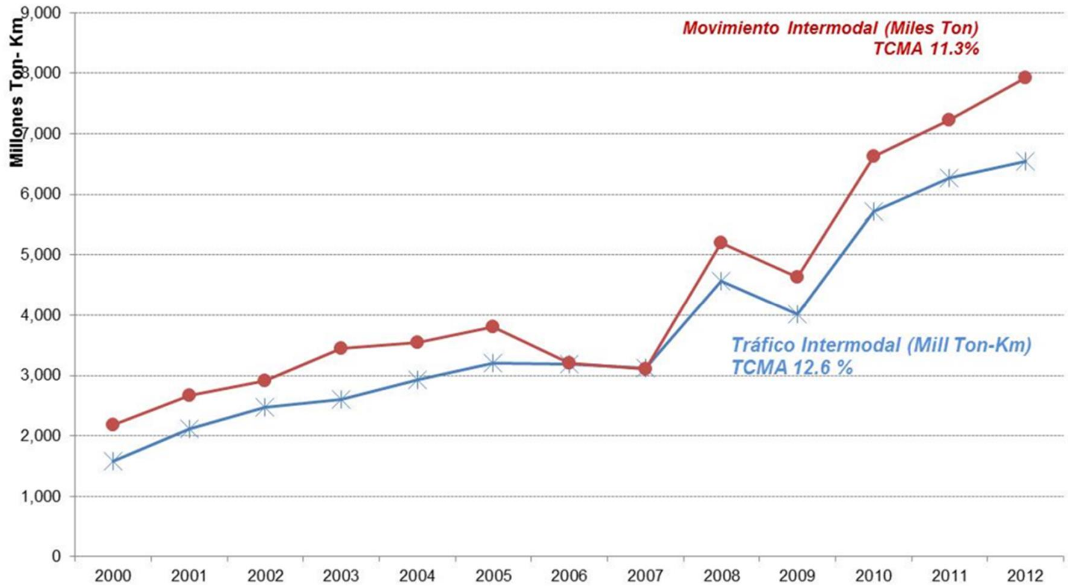
The recent trend in Mexico's intermodal transportation shows a high dynamism despite having gone through a strong global economic crisis between 2008 and 2009. Indeed, from 2000 to 2012, intermodal cargo moved by rail quadrupled, going from 2-8 million tons and from 1,600 to 6,500 million tons ï  kilometer.

This meant that the average growth rate for the period was 11.3% per year measured in tonnes and 12.6% per annum on the tonne-kilometers (figure 1). Incidentally, both far superior to the growth rates of trucking and rail, which were 1.5% and 4.2% annually respectively.

## 2 CONCEPTUAL DESIGN OF THE METHODOLOGY FOR ANALYSIS OF INTERMODAL CORRIDORS

One of the difficulties in conducting studies and systematic analyses of the behavior and evolution of intermodal transport was for a long time, the lack of detailed information of rail and truck, due to the cancellation of published data on supply-demand fluctuations, as well as on origins and destinations of freight flows, the generator and attractor nodes according to cargo type, the major regional and national routes, etc.

**Figure 1. Movement and intermodal traffic, 2000-2012.**




Source: Created by IMT based on data from the Directorate General of Railroads and Intermodal Transportation, SCT.

Moreover, not either was available a methodological tool to help know the movement of cargo in the terrestrial network, a necessary condition to identify intermodal corridors (Garcia et al, 2013). So, the proposed methodology represents a breakthrough in a clearly deficient aspect: the identification and the spatial representation of freight flows carried by rail and by the intermodal network and proposing a set of performance indicators currently available data are not used with an integrated approach.

This seeks to provide a method and an innovative tool for understanding this phenomenon, which integrates topology and roughness of the territory (Santos, 2000) with the quantitative and qualitative analysis of intermodal corridors, unlike existing approaches at present, generally with a purely qualitative focus, or at the best case, based on economic modeling, but lacking the spatial dimension (Rodrigue, 2012), except in the urban environment, also known as network's last mile, where a great variety of methodological proposals and refined models of urban freight distribution exist (Cedillo et al, 2014 y González et al, 2014).

Indeed, current metrics and methods in this issue, both in Mexico and in Latin America, usually reach aggregate data on flows transported and in the best case, examples of econometric models are found, whose refining can be important for economic and demographic data projections, but lacking of a basic dimension of freight flows, i.e. the territorial dimension (Fujita et al, 2000), where it is possible to verify the routes and the corridors, the infrastructure capacities, the modes used, the types of vehicles, the location of nodes for freight exchange or transfer and the more detailed characteristics of shipments moving between diverse regions.

For this reason both the approach as the proposed tool not only imply a practical contribution, but a conceptual one to measure the evolution of a theme as relevant today, nevertheless scarcely studied with hard data, such the transportation and intermodal corridors (Boske et al, 2003).

On the matter, it is intended that in the short term this methodology allows the generation of new information useful for diverse studies such as trip generation models or load distribution; the competitiveness in costs or travel times between the arrangements of the intermodal chains; the analysis of logistic or regional efficiency of supply chains, among others.

The methodological development that is presented, is structured around two key information inputs:

- Data on freight movements, which are the numerical records describing the reality on intermodal transport.

- Georeferenced information from the intermodal network in the country, i.e., roads, railways, stations.

Since that the spatial representation of both the exchanges recorded at the origin-destination matrix of intermodal cargo and the flows that lead to the conformation of intermodal corridors is the central part of the methodology, it was necessary first to structure the geographical base, core on which the methodology operates.

This task implied the revision of the lines representing the railway infrastructure, the addition of a large number of nodes or stations not included in the geographic base from which it split and construction of the connectivity properties of the network, necessary to meet the methodology's working purpose.

The application of the methodology, which is based on the operational functions of TransCAD and in the cartographical functions of a GIS, specifically ArcGIS, (García et al, 2012), allows:

- Differentiate nodes depending on the volume of interchange, whether of origin or destination.

- Identify the key nodes, i.e., those busiest regarding to volume, both in tonnes and tonne-kilometers.

- Highlight the major origin-destination pairs.

- The cartographical representation of origin-destination pairs by tons and ton-kilometer through desire lines.

- Define load distribution scenarios on the intermodal network, based on a model of freight assignment.

- Compare the use of intermodal infrastructure according to the flow density by tonnes or tonne-kilometers.

- Present through maps, the location and distribution of intermodal corridors and/or the formation of prospective corridors (by tonnes or tonne-kilometers).

## 3 CURRENT STATUS OF INTERMODAL CORRIDORS IN MEXICO

According to data analysis from intermodal cargo in 2011, 17 nodes with movements exceeding 50,000 tonnes per year were found, which concentrated 95% of interchanged volumes. Among these the Pantaco intermodal terminal in Mexico City stands out with the largest cargo volume, about 2.5 million tons (considering the volumes of incoming and outgoing cargo); followed by Pacific ports, Manzanillo, with nearly 2.3 million and Lazaro Cardenas with 1.8 million tonnes and Nuevo Laredo with about 1.8 million tonnes in the northern border (Figure 4).

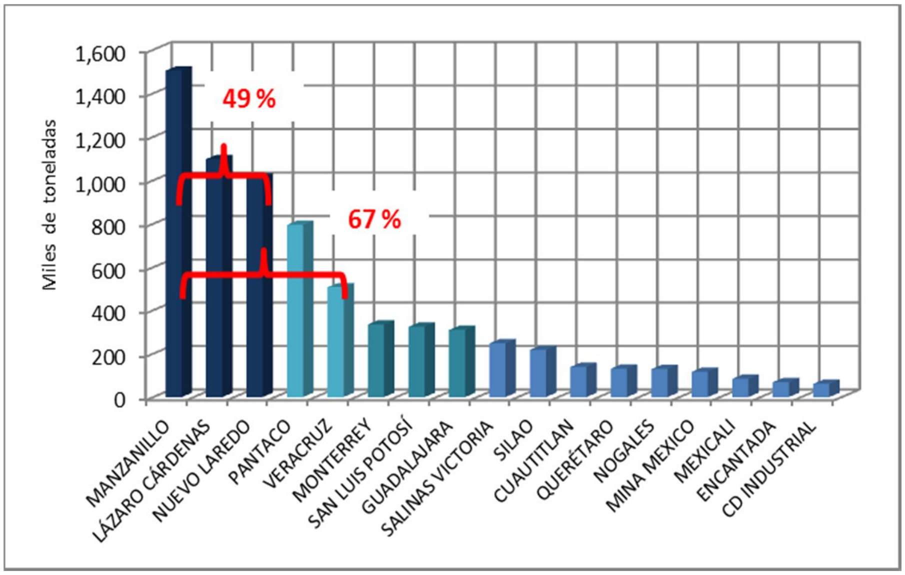
**Figure 4. Main nodes participating in the movement of intermodal freight, 2011.**

| Nodo | Origen | % | Destino | %2 | Total |
|---|---|---|---|---|---|
| PANTACO | 794,616 | 11 | 1,775,207 | 24 | 2,569,835 |
| MANZANILLO | 1,504,080 | 20 | 786,064 | 11 | 2,290,164 |
| LÁZARO CÁRDENAS | 1,096,963 | 15 | 768,848 | 10 | 1,865,825 |
| NUEVO LAREDO | 1,011,497 | 14 | 785,028 | 11 | 1,796,538 |
| VERACRUZ | 507,242 | 7 | 210,254 | 3 | 717,503 |
| GUADALAJARA | 309,365 | 4 | 316,098 | 4 | 625,468 |
| MONTERREY | 334,766 | 5 | 263,314 | 4 | 598,085 |
| SAN LUIS POTOSÍ | 323,716 | 4 | 242,158 | 3 | 565,879 |
| SILAO | 217,109 | 3 | 287,091 | 4 | 504,203 |
| SALINAS VICTORIA | 247,386 | 3 | 191,454 | 3 | 438,843 |
| QUERÉTARO | 131,022 | 2 | 306,716 | 4 | 437,740 |
| CUAUTITLAN | 138,644 | 2 | 236,183 | 3 | 374,829 |
| MINA MEXICO | 116,712 | 2 | 201,765 | 3 | 318,479 |
| ENCANTADA | 68,345 | 1 | 209,976 | 3 | 278,322 |
| MEXICALI | 83,918 | 1 | 184,909 | 3 | 268,828 |
| CD INDUSTRIAL | 61,310 | 1 | 176,619 | 2 | 237,930 |
| NOGALES | 129,136 | 2 | 47,532 | 1 | 176,670 |
| **SUBTOTAL** | **7,075,827** | | **6,989,216** | | **14,065,139** |
| **%** | **95.7** | **95.7** | **94.5** | **94.5** | **95.1** |
| **TOTAL** | **7,395,078** | | **7,395,078** | | **14,790,157** |

Source: Created by IMT based on 2011 data from the Directorate General of Railroads and Intermodal Transportation, SCT

From the perspective of the load generated (Figure 5), the sorting shows among the top five positions very important nodes of Mexican foreign trade: Manzanillo, Lazaro Cardenas, Nuevo Laredo and Veracruz, plus Pantaco in Mexico City, which is the big concentrating hub of intermodal freight in the country. These nodes together concentrate 67% of the load Intermodal volume (Morales, 2014).

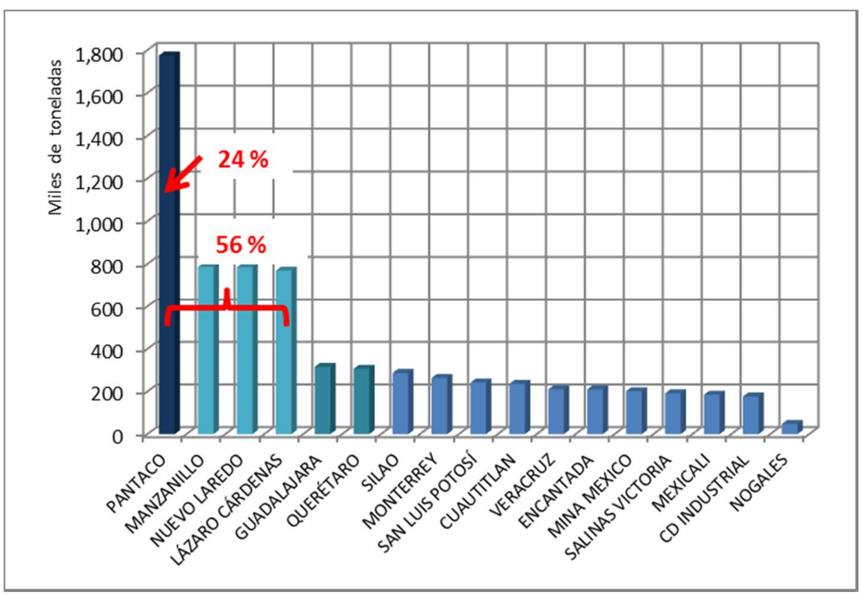
**Figure 5. Main emitting nodes of intermodal cargo, 2011**.




Source: Created by IMT based on 2011 data from the Directorate General of Railroads and Intermodal Transportation, SCT.

From the perspective of the nodes attracting freight (Figure 6), Pantaco receives by itself, almost a quarter of the containerized cargo, and adding to this the node movements from Manzanillo, Nuevo Laredo and Lazaro Cardenas volume equals to 56%.

**Figure 6. Main receiving nodes of intermodal cargo, 2011.**




Source: Created by IMT based on 2011 data from the Directorate General of Railroads and Intermodal Transportation, SCT.

The main trade relationships are limited to intermodal cargo flows from the ports of Manzanillo, Lazaro Cardenas and Veracruz to the center of the country (Figure 7). A significant density flows also between the northern border and the northeastern states and the center, such as Nuevo Leon, San Luis Potosi and the Bajio region. To a lesser extent, stand out the flows Mexicali to Guadalajara, San Juan de los Lagos and the center of the country.

**Figure 7. Desire lines of intermodal cargo in Mexico.**


Source: Created by IMT based on 2011 data from the Directorate General of Railroads and Intermodal Transportation, SCT.

An important contribution of the proposed methodology is the ability to model flows with geographical representation to detect in a hierarchical way, by ranks of flow densities , major intermodal corridors operating in the country and as well its variation over time. The assignment model on the intermodal network allows to conclude that in Mexico there are only three high density corridors consolidated, i.e. that mobilize more than one million tonnes annually; two of them are from the Pacific coast to the geographic, demographic and economic center of the country, the metropolitan area of Mexico City (MAMC), and the third corridor is from north to south (Figure 8), these are the following:

1. Manzanilloï Guadalajaraï Silaoï Queretaroï MAMC (figure 7) on this corridor, load is greater than 2 million tonnes.

2. Lázaro Cárdenasï Celayaï Queretaroï MAMC.

3. Nuevo Laredoï Monterreyï San Luis Potosiï Queretaroï MAMC.

**Figure 8. Main intermodal cargo corridors in Mexico, per tonne (Assignment model-IMT).**


Source: Created by IMT based on 2011 data from the Directorate General of Railroads and Intermodal Transportation, SCT.

It is important to note that when comparing the spatial representation of intermodal cargo flows of 2010 with that of 2011, the definition of runners is consistent, despite the increase in the annual volume of cargo.

An intermodal corridor that is emerging is the route Veracruzï MACM, where the charge density is between 500,000 and one million tonnes (figure 8). However, it might seem that evolution is fast considering that the intermodal volume on this route in 2010 was below 500 thousand tonnes.

From the standpoint of tonnes-kilometer, the corridor Manzanilloï Guadalajaraï Irapuatoï Querétaroï MAMC is the busiest and the tonne-kilometer level remains higher than 2,000 million along its path. Not so in the corridor that runs from Nuevo Laredo to the center, where the t-km level varies along its course, the higher is located between Monterrey and San Luis Potosí, and then between Querétaro and the MCMA which alternates with lower load intensity as shown in figure 9.

**Figure 9. Main intermodal cargo corridors in Mexico, per tonne-kilometer (Assignment model-IMT).**


Source: Created by IMT based on 2011 data from the Directorate General of Railroads and Intermodal Transportation, SCT.

Finally, since the chosen method has proven its functionality and usability, and the database showed consistency, it will intend to expand the possibilities of the methodology by generating performance indicators both for transportation as for intermodal corridors, aiming to enrich the systematic analysis of the evolutionary behavior of this sector with periodical contributions of highly relevant inputs to decision making.

## 4 A PRELIMINARY PROPOSAL OF PERFORMANCE INDICATORS OF INTERMODAL CORRIDORS

In previous analyzes of IMT (Martner et al, 2014), a series of tools for developing indicators data were identified. Besides those mentioned above, related to the volume of cargo, such as tons moved by the nodes of the network, the main origin-destination pairs of cargo and intermodal corridors of higher density (in tonnes and tonne-km ); currently available data are presented as dispersed and unsystematic, but that develop sets of indicators on the operation, efficiency and competitiveness of intermodal corridors in

Mexico and eventually consider that this basis of analysis could be replicated in other emerging countries in the region

In this regard, the proposal is to create a method or tool to measure consistently and periodically the performance and efficiency of the corridors, with a comprehensive vision, that is to consider the development of indicators covering the various links in the chain or intermodal network.

A general example of indicators that could be formalized in the analysis of a chain or intermodal corridor linking flows mobilized since the arrival of a ship to a seaport to the final destination in any city of the country is presented in the following paragraphs.

Generally, when a vessel arrives in port is directed to a dock to start the loading and unloading of goods transported. But sometimes must wait in the anchorage area before docking. To measure the performance of this phase, you can develop, with data available, indicators on the percentage of ships anchored by type of cargo and anchorage of the total time measured in hours or days, among others

When anchorage times higher load because the docks are busy are recorded, means that there is saturation in the port, so it will have to implement improvements in operation or expand the available for docking vessels infrastructure.

In Figure 10 on the anchoring of ships in Veracruz, a high percentage of agricultural bulk vessels must anchor for many hours, due to the occupation of docks is observed

**Figure 10. Time anchoring of ships in the port of Veracruz, January-August, 2014**

| TIPO DE CARGA | SHIPS AT ANCHOR | % OF SHIPS AT ANCHOR | TIME ANCHORING (HOURS) | ANCHORING PER VESSEL (HOURS) | ANCHORING PER VESSEL (DAYS) |
|---|---|---|---|---|---|
| GRANEL AGRÍCOLA | 50 | 38% | 4,958.00 | 99.16 | 4.13 |
| CARGA GENERAL SUELTA | 47 | 17% | 1,648.00 | 35.06 | 1.46 |
| CONTENEDORES | 38 | 8% | 790.00 | 20.79 | 0.87 |
| AUTOMÓVILES | 17 | 14% | 866.00 | 50.94 | 2.12 |
| OTROS | 21 | 26% | 527.00 | 25.09 | 1.05 |
| TOTAL | 173 | 15% | 8,789.00 | 50.81 | 2.12 |

Source: Created by IMT based on data from API Veracruz

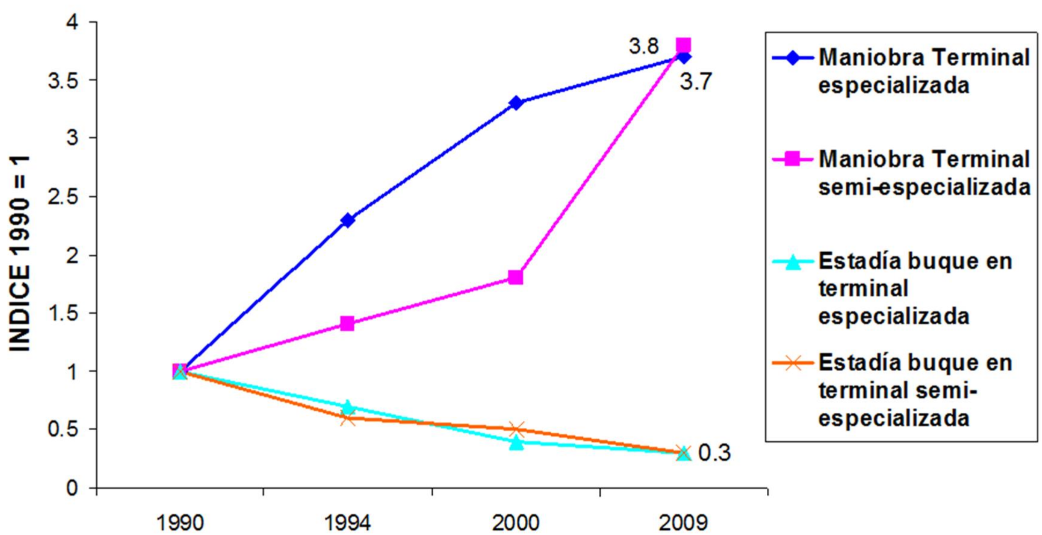
The second set of indicators that can be constructed with the available information corresponds to loading/unloading operations at the harbor. In this sense, indicators like the number of containers downloaded per each occupied crane or the number of containers per hour of each operated vessel are common data from the port's statistics for all countries in the region.

An improvement in these indicators has a favorable impact on others directly related. Indeed, the greater the numbers of loaded/unloaded containers per hour, ships spend less time at docks.

| |
|---|
| **Container / Hour Crane**<br>Port of Lázaro Cárdenas = 38 CHC en 2014 (first half)<br>Port of Puerto Progreso = 30 CHG en 2014 (first half)<br><br>**Container / Hour / Vessel in Operation**<br>Port of Lázaro Cárdenas = 113 CHVO en 2014 (first half)<br>Port of de Veracruz = 80 CHVO en 2014 (first half) |

It should be noted that, since starting the port restructuring in Mexico (1993), the return indexes on loading and stay of the ship in the docks have substantially improved, that is why it is said that one of the main achievements of this structural transformation is in the high efficiency achieved in the first maneuver (yard ship and vice versa).

**Figure 11. Port of Veracruz**
**Performance Index loading/unloading container vessel and Index container vessel stay time at Port**




Source: Authorʻs own elaboration with data from CGPMM

However, a critical datum is the residence time of cargo at the port, before being sent to its destination. At this stage, also called second maneuver (storage yard to terrestrial vehicle or vice versa), concur lot of actors and activities related goods inspection, sorting of cargo, the payment of duties, customs inspection and clearance of loads.

All these activities, which are or should be related to trade facilitation issues, represent a huge window of opportunity to improve the regulation and practices that currently predominate.

Indeed, the average time spent cargo container terminals in major national ports fluctuate around 7 days except Lazaro Cardenas that reports about 5 days on average.

**Time spent in the container terminal**

- Ɇ stay time in container yards / Ɇ Total operated containers
- 
- Puerto Manzanillo 2013 = 5.77 days
- Puerto Manzanillo 2014 = **6.88** days
- SSA Manzanillo 2014 = 6.42 days

Previous analyses (Martner et al, 2013) have mentioned the factors that affect this indicator. Among these stand out:

ÅA complex circuit of revision causing the extension of cargo stay at port

ÅThe resulting tension between the imperatives of fluency in foreign trade and security imperatives

Å An information and documentation circuit poorly integrated to the "second maneuver" logistics

ÅInadequate logistics practices from small and medium exporters

ÅLack of integration of the logistics port node to the land modes

On the other hand, the load's stay time directly influences on the dynamic capacity of storage yards and on port occupancy percentage. Indeed the more stay time, the less is the dynamic capacity and more the occupancy rate of port's storage areas.

**Dynamics Capacity (DC) in the maritime terminals**
**DC = (365 / Average stay) * static capacity**

Puerto Manzanillo 2014 = 2.90 million TEUs
SSA Manzanillo 2014 = 1.42 million TEUs

Finally, it is important to measure the evolution of the efficiency and competitiveness of the connections with the hinterland. According to recent studies (Notteboom, 2008, Rodrigue et al, 2010), proper connection to the hinterland is key to the development of ports. In fact it is considered that, largely, the competitive battle between ports is increasingly fought on land. Therefore, the hinterland connections through the development of corridors and intermodal services are a key area for competition and coordination between actors (Notteboom, 2008).

**Indicators of the intermodal chain**

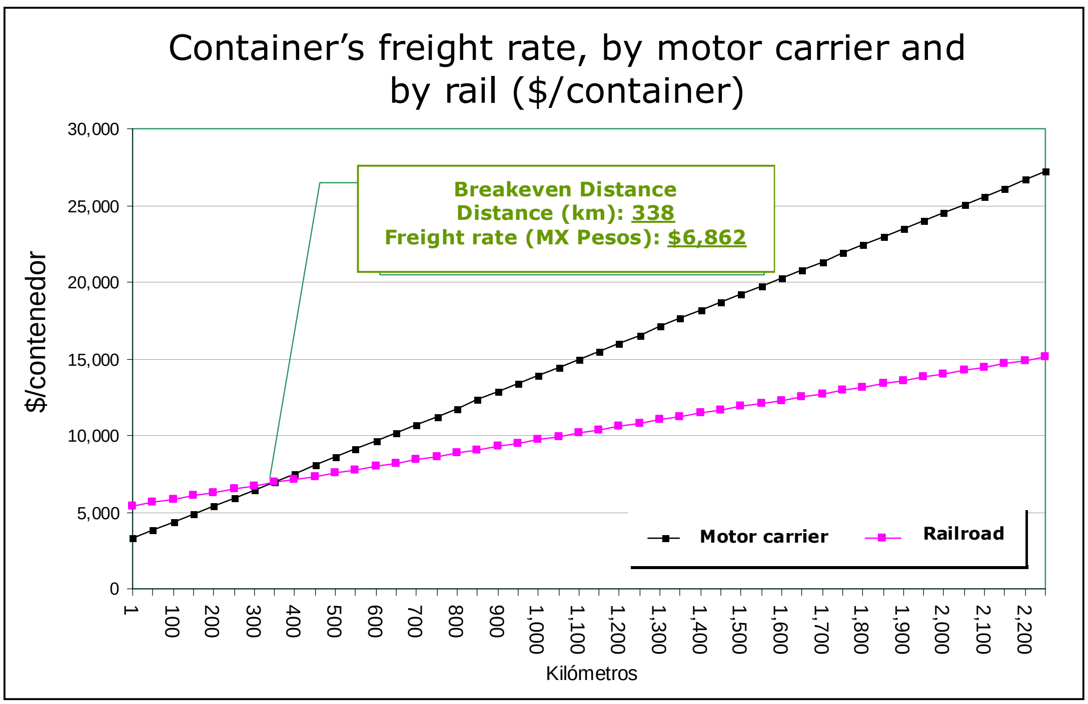
- Competitiveness of Intermodal vs Truck
- Cost of inland transport
- Travel Time Indicators (Truck-FFCC)
- Commercial speed
- Frequency and Reliability of Service
-% Time delivery

In Mexico, the consolidation of corridors and the services of intermodal double stack trains have greatly improved connectivity to the main national ports, continually expanding their hinterlands.

The following example shows the competitiveness of double-stack rail on relatively short distances. Indeed, Figure 5 shows that around 340 km of rail transport can compete successfully with the truck in the movement of containers. Therefore, there is a very large potential of development of such services not only in the Pacific coast but also in the Gulf coast in view that Veracruz and Altamira have their main markets at distances ranging from 400 potential and 500 kilometers.

This level of competitiveness corresponds to data for major intermodal corridors where double stack trains operate with capacity near 300 TEUs, in convoys of 80 or more cars.

Technological, operational and infrastructure changes in intermodal transport shift the equilibrium boundary down (to left)




Source: IMT's own elaboration,with field gathering data and logistic operators information. In Mexican pesos $, 2010.

Other indicators to analyse the performance of intermodal corridors respect to the linking their hinterland are the travel times of the terrestrial modes of transportation (truck-railroad), the commercial speed at freight corridors, as well as the frequency and reliability of the intermodal services. To do this, the participation of the new regulatory agency for rail and multimodal transport in Mexico and other government or private agencies that collect information on the operation of transport in Mexico is required.

## 5 FINAL THOUGHTS

While it is true that the formation of intermodal corridors can be seen as an emerging industry in Mexico, the same occurs for the high potential of their development in the immediate future (Martner, 2007).

However, currently there is no tool allowing a constant analysis of intermodal transport in Mexico. In the best case, there are only segmented and isolated data on the phenomenon in question and many of them are not collected on a systematic or continuous way along the time.

The conceptual and methodological contributions have been insufficient in this topic Recent efforts to study the behavior and evolution of intermodal transport are performed in the best case, based on econometric models that estimate volumes and types of goods that could be switch between different regions, but lacking the ability to localize flows geographically in particular spaces, nodes or networks, or under certain multimodal combinations. This diminishes the analytical strength when, for example, there is interest to evaluate the operation of an intermodal corridor, establish its hierarchy within the national network, determine its saturation horizon, the need for capacity expansion or construction of new infrastructure, among other aspects.

By contrast, from the conceptual view, the proposed methodology represents a progress in a clearly deficient aspect: the identification, representation and spatial analysis of cargo moving through the Mexican railways and intermodal networks, providing a method and a new tool in Mexico and countries in the region, which integrates the topology and roughness of the territory with the modeling and quantitative analysis of intermodal corridors, unlike existing approaches at present which are either only qualitative type or at the best case, are based in economic modeling, but lack the spatial dimension.

Thus the preparation and implementation of a robust methodology with a quantitative focus acquires relevance, because allows a regular and continuous analysis of developments and trends in this sector and, in this way, promote the planning instruments and the public policies to help drive the competitiveness of nodes and arcs of the network, because it cannot be forgotten that consolidating of corridors depends on the efficiency and competitiveness of intermodal systems versus single-mode systems, dominated by road transport today.

No less important is the fact that the proposed methodology proposes the development of a set of indicators to periodically measure the performance of intermodal corridors in Mexico. This implies, in a second phase, the need to create a National Observatory of Transport and Logistics as the institutional framework for the use, development and dissemination of the proposed methodology.

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